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October 12, 1999

Docket Management
Room PL-401
400 Seventh Street, SW
Washington, DC 20590
Fax: (202) 493-2251

Re: Docket No. 99-5100-9

Gentlemen:

You may already have the enclosed study published by the Society of American Engineers Inc., but if you haven't studied the findings, I urge you to do so, as the conclusions are Profound!

Lap/shoulder usage for children of all. ages minimizes potential for head injury and reduces. the risk of abdominal injury, vs. lap belt only. The differences are statistically significant!

Therefore, in the "real" world, children will. continue to use adult lap/shoulder belts, but because the shoulder belt does not fit properly, they will continue to not use it, thereby substantially increasing the risk of injury.

SHOULDER BELT POSITIONERS REMEDY THIS PROBLEM WHILE NOT DEGRADING THE EFFECTIVENESS OF THE BELTS!

Thank you for your consideration.

Sincerely,

Robert E. Capps
President

Enclosure (5 pages)

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Children in Adult Seat Belts and Child Harnesses: Crash Sled Comparisons of Dummy Responses

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Post-it® Fax Note 7671	Date 10-12 # of pages ▸ 5
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ABSTRACT

Many children are still restrained in adult belts alone, even though an adult seat belt is not optimal for small occupants for whom a child restraint would be safer and more desirable. Therefore, a test program was designed to investigate the impact responses of three dummies representing children aged 18 months, three years and six years. The simulations were sled runs at a delta-V of 48 km/h with accelerations of 27 g. The dummies were restrained in adult lap/shoulder, lap-only and child harness belt systems.

Neck shear, axial tension and bending moments were rather higher with a lap/shoulder than a lap-only belt. However, the lap/shoulder system minimised dummy head and upper torso excursion, head acceleration and pelvic accelerations.

Lap belt loads, head accelerations, HIC and chest accelerations were higher with the lap belt alone than with the lap/shoulder belt. The lap belt also permitted considerable excursion and head contact with the hard frame of the test seat, which affected HIC and neck loads. The lap/harness system gave generally the highest head and neck forces.

INTRODUCTION

CONCERNS ABOUT CHILDREN IN ADULT BELTS - It is well accepted that any child riding in a passenger vehicle should be restrained in a dedicated restraint system of a type appropriate to the child's size and age. Surveys indicate that until the child weighs more than 36 kg, or has a sitting height of about 760 mm (roughly equivalent to an age of 11 or 12 years), the seat belt will not fit in an ideal manner.[1] Where appropriate for the age and size of the child, a child restraint or booster is more desirable than an adult belt used alone.

Nevertheless, the fact is that countless children throughout the world, although best suited to child restraints, commonly do ride in motor vehicles while restrained only by adult seat belts. It is a reasonable expectation that from time to time vehicles with children thus restrained will crash. It would be a matter of great concern if this mismatching led to a commensurate increase in risk of injury to the restrained child.

Studies of the effects of adult belts on child injury reduction and injury patterns are rare. As it happens, available epidemiological data do not point to restrained children of at least ten years or so being at especial risk.[2] However, predictions of injury risk (especially for smaller children) are based on a narrow knowledge base. This paper reports laboratory data that are intended to build on existing knowledge.

The testing was performed in the context of recently completed field studies of real-world crashes in Australia. Results of these studies have previously been reported.[3][4][5] Throughout the entire sample of children, in all kinds of crashes, dedicated child restraints generally performed the best. As would be expected, children without restraints fared badly.

Table 1 summarises the results of this study. Note that while the percentages of children sustaining MAIS 2+ injuries in lap/shoulder and lap-only belts are not significantly different, all but four of the the lap-only belted children were in centre seats in the centre rear and should therefore for that reason have demonstrated a lower risk of injury. Similar logic was used in a major Swedish study to suggest that a centre-seat lap-only belt is not as effective in preventing injury as a lap/shoulder belt.[6] and Langweider and Hummel (1994) documented a MAIS 2+ child injury rate of 29.8% for lap/shoulder belts and 42.9% for lap-only belts.[7] Further, in the Australian study there was a significantly greater incidence of belt-induced abdominal injury among lap-belt wearers than lap/shoulder belt wearers (eight out of 35 children, 23%, as opposed to 10 out of 121 lap/shoulder belted children, 8.3%). This difference is statistically significant ($p<0.02$).

Results from this field study indicated that while dedicated child restraints offer young children the best crash protection, adult lap/shoulder belts provide acceptable protection for children in most crashes. The most serious belt-induced injuries observed were minor superficial bruises and abrasions. The work confirmed earlier findings from Australia and elsewhere that children - even very small ones - can be well protected in severe crashes when using lap/shoulder seat belts, although the use of child restraints is a safer and more desirable option.[4]

Table 1.
Summary of Results: NSW Field Study, All Restraints

	Child restraint		Lap/shoulder belt		Lap-only belt		No restraint	
MAIS	N	%	N	%	N	%	N	%
0	28	39.4	11	9.1	5	14.3	0	0.0
1	30	42.3	83	68.6	21	60.0	6	31.6
2	7	9.9	13	10.7	3	8.6	3	15.8
3	1	1.4	7	5.8	2	5.7	5	26.3
4-5	2	2.8	1	0.8	1	2.9	0	0.0
6	3	4.2	6	5.0	3	8.6	5	26.3
Total	71	100.0	121	100.0	35	100.0	19	100.0
MAIS 2+	13	18.3	27	22.3	9	25.7	13	68.4

FOR THE PRESENT SLED STUDY, -

Studies have indicated that lap-only belts promote the risk of child occupant injury through increased excursion of the head and torso.[8] Many others have drawn attention to the risk of injury to the abdomen and lumbar spine through direct loading of the lap belt.[9][10] However, it has also been suggested that to restrain the upper torso, especially that of a child, places the neck at greater risk than if the torso is allowed to swing unrestrained. Anatomical considerations,[11][12] coupled with case reports of cervical spine injury to forward-facing children [13][14] have caused considerable international attention to be drawn to the issue of cervical and high thoracic spinal cord injury to infants and young children in forward-facing restraint systems.

However, data searches in Australia have failed to show that the lap/shoulder seat belt poses a significant threat to a child's spine, and field studies have indicated that concerns about vulnerability based on purely anatomical considerations may be misplaced. In the field study outlined above, neck injury in children using adult lap/shoulder belts was not found to exceed very minor degrees of severity.

The present test program was designed to supplement the field observations made during the Australian field study by investigating the responses of the 18 month CRABI, three-year-old Hybrid III, and six-year-old Hybrid III dummies when restrained in adult lap/shoulder, lap-only and child harness belt systems. This paper documents the data from these comparative series of laboratory sled tests.

METHODOLOGY

The sled tests were all conducted in the *Crashlab* facility of the Roads and Traffic Authority of New South Wales on an MTS Monterey "Impac" rebound sled at a nominal change of velocity (delta-V) of 48 to 49 km/h (30 miles/hr).[1] The configuration of this sled gives rise to a short-duration, near-sinusoidal pulse, with a rapid rise of acceleration. For the given delta-V, although comparisons of one restraint system with another are valid, these tests represent a violent and rather "stiff" crash. The peak sled acceleration for all runs was within the range 26.8 g to 27.5 g, typically peaking at 40 ms after first contact with the decelerator piston.

Three anthropomorphic dummies were employed, representing for the desired age ranges the most biofidelic examples currently available.[2] They were as follows.

- CRABI ("Child Restraint Airbag Interaction") Eighteen-month Old Infant Dummy (Version 1).
- Hybrid III Three-year-old Dummy (prototype status, in verification testing stage, especially made available for this research by First Technology Safety Systems).
- Hybrid III Six-yew-old Dummy (Model 127-0000).

Their basic dimensions are shown in T&e 2.

Table 2.
Basic Dimensions, Child Dummies

Dummy	Weight		Erect sitting height	
	kg	pounds	mm	inches
CRABI 18-month Old	11.2	24.7	505	19.9
Hybrid III Three-year-old	14.5	32.0	546	21.5
Hybrid III Six-year-old	22.8	50.2	640	25.2

Following calibration sled runs, each of the three dummies was tested with a lap/shoulder belt and a lap-only belt. A child harness in conjunction with a lap-only belt was tested with the 3-year old and 6-year old dummies, but not with the 18-month CRABI dummy. There were two sled runs for each configuration. The seat belt or harness was replaced by a new one after each run. The acceleration/time characteristics of each run were measured by accelerometers mounted on the sled.

The lap/shoulder belt in each case was of running-loop configuration, with a dual inertia-locking and webbing-sensitive emergency-locking retractor (as required in

1 The original protocol required runs at 56 km/h, but calibration tests revealed the probability of damage to the dummies in the lap-belted configuration at this delta-V.

2 All the child dummies were manufactured by First Technology Safety Systems Inc. of Plymouth, Michigan.

NOTE: LAP/HARNESS NOT TESTED Below 3 yrs. old.

Australian cars) mounted at the upper end of the shoulder belt. The positioning of the belt anchor points was in accordance with the requirements of Australian Standard 3629.1-1991, Methods of testing child restraints; Part 1: Dynamic testing. [15] This positioning is consistent with the Australian Design Rules covering seat-belt anchorage *geometry*

The seat used for the tests was a stylised generic rear passenger-vehicle seat, also in accordance with the requirements of Australian Standard 3629.1-1991. The required base of this seat is a polyurethane slab, density 28-29 kg/m³, 156 mm thick, on a rectangular frame. The seat back is 70 mm thick.

All three dummies were instrumented as follows:

- head acceleration: 3-axis accelerometers;
- upper neck forces and moments: 6-axis transducers;
- chest acceleration: 3-axis accelerometer,
- pelvis acceleration: 3-axis accelerometer.

In addition, the lumbar region of the 18-month CRABI carried a 6-axis transducer for forces and moments. Belt force transducers were mounted on the webbing straps and buckle mounts. Sign conventions, head acceleration coordinates and data filter classes were as specified in SAE J211.[16] The condition of the dummies was monitored after each test by visual inspection and instrument checks. Feces were painted to detect contact points.

All runs were filmed by a stationary high-speed camera positioned to the side of the sled. The cameras were operated at 1000 frames per second.

RESULTS

OVERVIEW - A complete tabulated set of the responses obtained from each dummy in each test is given in a full report to project sponsors. [17]

SLED TEST DATA FOR THREE DUMMIES - To support and build upon existing field data, the objective of the sled study was to assess the effects of using three-point lap/shoulder seat belts for the restraint of a selection of child anthropomorphic test dummies, in comparison with the effects under the same test conditions but using lap-only seat belts. Another series of runs compared these results with the effects of using a child harness. Particular attention was paid to head and neck forces and seat-belt loads. This appears to be the first time that such direct comparisons have been undertaken in a systematic manner.

Head excursion allowed by the lap-only belt for all three dummies permitted head contact with the seat. This was a test structure with a wooden frame, and typical of a real car seat in its general relationship to belt mounting points rather than in construction. These contacts gave generally high readings for HIC and neck loads.

The sled test data for the three dummies showed mixed results for neck responses: shear, axial tension (see Figure 1) and bending moments (Figure 2). Except for axial tensile forces in the two larger dummies and neck moments in the 18-month CRABI, the tendency was for the lap/shoulder and lap/harness systems to result in rather higher readings than the lap-only belt.

Figure 1 - Neck axial tension +Fz (kN)

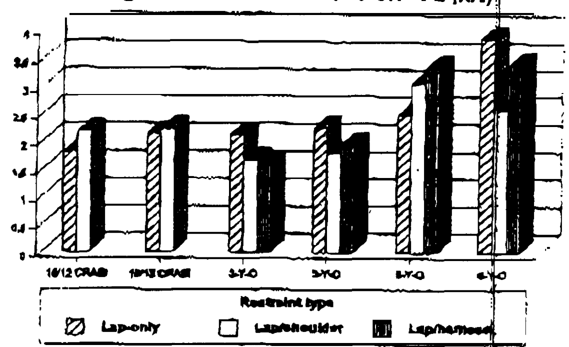


Figure 2- Neck forwards moment +My (Nm)

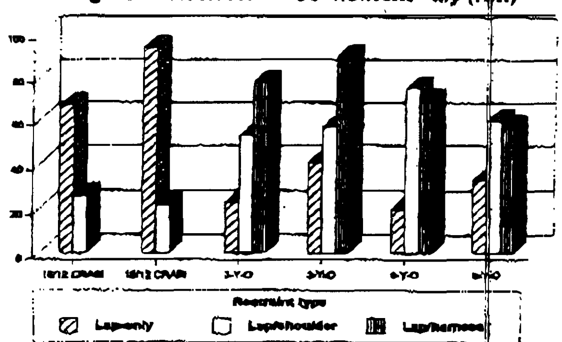
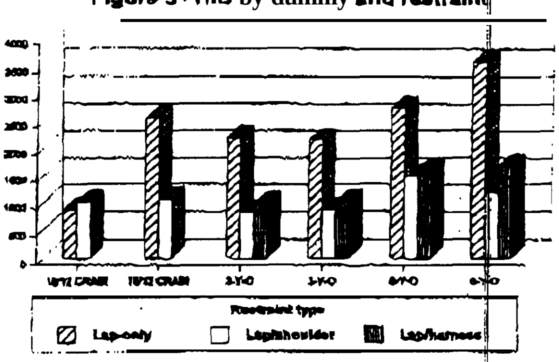


Figure 3 - HIC by dummy and restraint



However, the lap/shoulder system, as well as minimising dummy head and upper torso excursion, was effective in minimising head acceleration and pelvic accelerations.

Head accelerations, HIC (Figure 3), chest accelerations and lap belt loads were consistently higher with the lap belt alone than with the lap/shoulder belt. The absence of upper torso restraint in the lap-only system allowed excessive excursion of the Hybrid III 3-year old and 6-year old and consequential head contact with the seat frame, but it did minimise dummy neck and chest response,

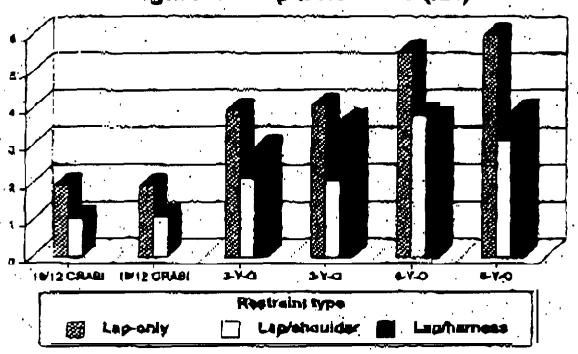
. Of all the dummies, only the 18-month CRABI was not correctly held in place by either. restraint during the entire crash sequence. In the lap belt tests, the dummy was allowed to rotate up and over the lap belt. In the lap/shoulder tests, the dummy's upper torso "fell out" of the shoulder portion of the restraint at the end of the crash sequence. It is possible that this is a factor of a diffarince in biofidelity between the CRABI and Hybrid III dummy range. It is more likely to be a reflection of the different weights, segment length and mass disuibution between dummies representing the anthropometric difference between toddler and young children, and is therefore possibly relevant to the real world.

For the CRABI 18-month dummy the results suggest that the lap/shoulder system minimises head acceleration and therefore HIC and forward bending moment of the neck. The lap-only belt minimised neck, loads, chest and pelvic accelerations, These results directly relate to the lack of upper torso restraint. Although the absence of an upper torso restraint reduces neck loads on the dummy, it allows excessive excursion of the upper torso and head.

There' was a consistent tendency for neck forces to be highest in runs with the lap/harness system. Head accelerations and HIC were also high in the lap/harness system, even in the absence of the head contacts that affected results from the the lap-belt runs. This indicates the need for some attention to the design of the lap/harness system. Unlike the configuration in a forward-facing child seat, the shoulder straps of the child harness when used with a lap belt are anchored directly to the vehicle structure. In a child seat, the harness is attached to the seat and the seat attachments are separate. The lap/harness configuration is therefore comparatively stiff in its reaction to crash forces, and this may be why the dummy neck loads were high in these tests. This suggestion is supported by outputs for chest accelerations, which were also highest in the lap/harness configuration.

Lap belt loads were much higher with the lap-only system in all runs. This is not surprising, but more unexpected were generally higher loads in the lap belt in conjunction with a harness than with a shoulder belt (Figure 4).

Figure 4 - Lap belt loads (kN)



Because of limited data on biomechanical tolerance data and anthropomorphic child dummy biofidelity, the absolute dummy responses should be assessed cautiously in relation to their validity for the real world. Unfortunately, the neck of the Hybrid III dummy - having been designed very much with flexion and extension as priorities [18] - is poorly biofidelic in regard to axial forces.[19] Essentially it is too stiff. That could be one explanation for the rather similar and non-discriminatory values for head acceleration and for for +Fz tensile forces for all the sled tests for all three child dummies (which are constructed along the lines of others in the Hybrid III range) reported in the present paper. The child dummies we used, although the most biofidelic available, are also deficient in other aspects of biofidelity, in particular in the pelvic and abdominal regions.

CONCLUSIONS

In summary, accepting some incpnsistencies in the results from dummy to dummy, the results are in accord with the field data; broadly, that in comparison to lap-only belts, lap/ shoulder belts

(i) minimise head excursion and therefore reduce the potential for head injury; and

(ii) produce lower loads in the lap portion of the restraint system and therefore reduce the risk of abdominal injury.

There is nothing in this set of sled test results to indicate that adding a shoulder belt to a lap belt places a child at a higher risk of serious neck injury from inertial forces. Taking account of the whole range of results, the lap/shoulder configuration generally gave the most favourable dummy responses.

The results also indicate, however, that the simple addition of a harness (twin shoulder-belt) system to a lap belt, although reducing excursion of the head and torso, may lead to neck forces that are higher than those seen in the lap/shoulder belt configuration, as well as head accelerations that are slightly higher. Another problem with the harness/lap-belt configuration is that the shoulder belts can pull upwards on the lap belt, and this may increase the potential for submarining. The comparatively high readings for head and neck forces and accelerations indicate the need for some attention to design. The main need appears to be, to lessen the stiffness of the system's response to crash forces. without increasing excursion more than necessary. Most of the dummy responses in the lap/shoulder configuration were more favourable than in the lap/harness configuration, which is an unsatisfactory situation because not only are harnesses commonly used on their own, they are also used in association with booster seats, especially in the centre rear seating position.

The 18-month CRABI dummy was not well restrained in either of the adult belt systems. This emphasises the importance of using dedicated child restraints up to the age of at least two years and desirably, as stated earlier, until any child becomes too large.

The best adult restraint system overall, as indicated by the present series of sled tests, is the lap/shoulder system if an adult belt has to be used by a child for any reason. The lap belt offers a higher potential for abdominal and head injury through high webbing loads and extensive head excursion, and the lap/harness system appears to raise neck loadings to a level in excess of the lap/shoulder system.

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